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EFFECT OF PILLAR ORIENTATION ON STABILITY

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by

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ABSTRACT

In March 1982 a series of rockbursts occurred at the Quirke Mine of Rio Algom Ltd. at Elliot Lake. Prior to these rockbursts, deterioration of pillars was observed as well as cracks in the floor. This deterioration was caused by high stress concentrations at specific locations in the pillars and floor. In some cases minor modifications in pillar orientation could reduce the high stress concentrations which would be useful in the design of new room-and-pillar panels.

A boundary element computer program was used to model different pillar configurations, first to show why pillar spalling and floor heave occurred at specific locations and then the effect of altering pillar orientation.

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LES EFFETS DE L'ORIENTATION DES PILIERS SUR LA STABILITE

par

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RÉSUMÉ

En mars 1982, il se produisit une série de secousses à la mine Quirke de Rio Algom Ltée, à Elliot Lake. Avant que les secousses se produisent, on avait observé que les piliers s'étaient détériorés et que le plancher contenait des fissures. Cette détérioration était due à de fortes concentrations de contrainte à des endroits précis des piliers et du plancher. Dans certains cas, de légères modifications dans l'orientation des piliers pourraient réduire les fortes concentrations de contrainte, ce qui pourrait s'avérer utile pour la conception de nouvelles chambres isolées à piliers.

On a utilisé un programme informatisé sur l'élément "limites" pour modéliser diverses configurations de piliers, pour montrer d'abord pourquoi les piliers se sont crevassés et les planchers ont gonflé à des endroits précis puis ensuite pour démontrer les effets des modifications dans l'orientation des piliers.

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MINING BACKGROUND

Quirke Mine is located on the north limb of a broad syncline. The main uranium-bearing conglomerate reef, 3 to 6 m thick, dips to the south at about 20°. Quartzite beds both overlay and underlay the reef. Fig. 1 shows part of the mine plan, centred on the area where rockbursts were initiated. A room (or stope) and pillar method is used in two types of layouts. The conventional layout is to leave rib pillars on dip and sill and crown pillars on strike at the bottom and top of the stopes. Jacklegs are used for drilling and slushers for removing the broken ore. In the centre of the area shown in Fig. 1 a local roll in the orebody resulted in a gently-dipping block of ore. This area was mined by trackless methods and pillars were left at an orientation between dip and strike. These are called apparent dip pillars. This latter method is used extensively to mine an upper reef at Quirke Mine.

The pillars have mainly vertical walls at Quirke Mine. This means that the angle between walls, roof and floor for rib pillars on dip is 90°. For strike pillars the angle between walls, roof and floor is 70° or 110° for a 20° dipping orebody, and apparent dip pillars vary between these two limits.

In situ stress measurements in the Elliot Lake mines (1) indicate that the horizontal principal stress are greater than the vertical stress which is equivalent to the weight of the overlying strata. In the east-west direction (strike) the stresses are 2.0 to 2.5 times the vertical and in the north-south direction (across dip) about 1.5 times the vertical.

EXPERIENCE AT QUIRKE MINE

Pillar deterioration was first observed on the 7 sill drift between 775 and 782 stopes in early 1981. The top up-dip corner of the drift was the first place to spall as illustrated in Fig. 2, followed by cracks in the bottom

down-dip corner as shown in Fig. 3. In the intervening months pillar spalling extended to the down-dip side of the crown pillar and the up-dip side of the sill pillar as illustrated in Fig. 4 and 5, respectively. In the trackless area spalling occurred at the pillar wall-roof corners on both sides, but was more prevalent on the down-dip side. The top and bottom of the centre rib pillars in the conventional stopes began to crush as shown in Fig. 6. Floor cracks were observed at the bottom of 775 and 779 stopes as illustrated in Fig. 7, as well as in the trackless area.

With the onset of rockbursts, pillar failure in some cases extended over the complete pillar height and width, of which Fig. 8 is an example. Around the periphery of the rockburst area spalling and cracks appeared on the top up-dip corner and bottom down-dip corner of the sill drifts, similar to the first observations in the 7 sill drift. Floor cracks turned into floor heave, in some cases with an uplift of almost 1 m as illustrated in Fig. 9. Floor heave was also observed in the floor of the 7 sill drift, as shown in Fig. 10, and the steel beams supporting ventilation doors in this drift were buckled in both the vertical and horizontal directions as shown in Fig. 11.

These observations indicated that due to mining the principal stress direction had changed from horizontal to more-or-less perpendicular to dip. Since the pillar walls are vertical this produces high stress concentrations on some of the pillar corners, especially those orientated on strike and to a lesser extent the apparent dip pillars.

BOUNDARY ELEMENT MODELS

The boundary element computer program is well described in the literature. The program on the computers of Rio Algom and CANMET is based on the published program of Hoek and Brown (2) which has been expanded up to 200

elements. It can be used to determine the stresses and displacements in two-dimensional layouts, where the length of a pillar or opening is long compared to its width. Also the rock is considered as homogeneous, isotropic and linear elastic.

Boundaries of single or multiple openings are divided into a number of elements. Major and minor principal stresses are calculated at the centre of each element and at points in the solid rock perpendicular to the boundaries. Corners of the openings are normally rounded, because sharp corners are not usual underground and also it allows calculation of stresses perpendicular to the corners.

The computer program contains both a shear and tensile failure criteria as follows:

$$\text{Shear failure } \sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2} \qquad \text{Eq 1}$$

where, σ_1 = major principal stress at failure

σ_3 = minor principal stress

σ_c = uniaxial compressive strength of the intact rock

m and s = empirical constants

$$\text{Tensile failure } \sigma t = 1/2\sigma_c(m - \sqrt{m^2 - 4s}) \qquad \text{Eq 2}$$

The uniaxial compressive strength for quartzite rock is taken as 179 MPa (26,000 psi) from laboratory testing. Values for 'm' and 's' were chosen as 3.5 and 0.1, respectively. These values were obtained from boundary element models of a shaft at Elliot Lake where failure and spalling of the shaft walls had occurred.

Two sets of models were run. The first investigated the stress distributions and stability of crown and sill pillars and the second was concerned with rib pillars on dip and apparent dip.

CROWN AND SILL PILLARS

The present layout of crown and sill pillars is shown in Fig. 12a for a 3 m (10 ft) thick orebody dipping at 20°. Crown pillars are generally 3 m (10 ft) wide, and sill pillars 4.5 m (15 ft) with a 3 m (10 ft) wide sill drift inbetween. Safety factor contours are shown in this Figure and are obtained from Equation 1 by dividing the right-hand side of the equation by the left-hand side. Pillar spalling is indicated at four locations (safety factor less than 1.0): the up-dip roof corner and down-dip floor corner on both the crown and sill pillars. These predicted locations of pillar spalling are identical to the observed conditions as illustrated in Fig. 2, 3, 4 and 5. At the centre of the pillars the safety factors are 1.0 to 1.5 for the crown pillar and 1.5 to 2.0 for the sill pillar.

The safety factor contours also indicate that the floor of the sill drift and the floor at the bottom of the up-dip stope should fail or are close to failure. It is interesting to note that floor cracks and subsequent heaving were first observed at these locations as illustrated in Fig 10 and 7.

One possible modification to pillar layout is to make the up-dip walls of both the crown and sill pillar perpendicular to the dip of the orebody rather than vertical. This layout is shown in Fig. 12b. The down-dip pillar walls remain vertical since otherwise it would create an overhang. Cross-sectional areas of the pillars are the same as in the first model, although the area in contact with the roof is reduced.

In this model stability at the centre of both pillars is improved with safety factors increasing to 1.5 to 2.0 for the crown and over 2.0 for the sill pillar. However, pillar spalling now extends over the complete length of the perpendicular walls and still remains at the roof corners of the vertical walls.

Figure 13 shows the magnitudes and directions of the principal stress as it passes through the pillars. At the centre of both pillars the orientation of this stress is 35 to 40° down-dip of the vertical, rather than perpendicular to the orebody as originally assumed. This orientation reflects the influence of the horizontal stress field which is greater than the vertical gravitational stress field. It is interesting to note that stress measurements in rib pillars at the Nordic Mine at Elliot Lake indicated principal stress directions 40 to 48° down-dip of the vertical (1). Under these conditions the most favourable orientation of the crown and sill pillar would be 40° down-dip of the vertical to allow unrestricted passage of the principal stress. This pillar orientation is not feasible, consequently, not much is gained by the pillar orientation shown in Fig. 12b. Pillar stability could probably be better improved by increasing the width of the pillars, especially the crown pillars.

RIB PILLARS

The first model run was for a rib pillar 3 m (10 ft) wide by 4.5 m (15 ft) high oriented on dip. The safety factor contours for this model are shown in Fig. 14a. Minor pillar spalling could be expected in the roof and floor corners of the pillar. Across the centre of the pillar the safety factor is between 1.0 to 1.5.

Figure 14b shows the same size pillar under identical loading conditions oriented along strike (or apparent dip) where the orebody dips at 20°. In this case failure would extend across the complete pillar width from the top left-hand corner to the bottom right-hand corner. These results indicate that larger sized pillars are required when the stopes are laid out along strike or on apparent dip compared to the conventional stopes on dip.

Fig. 14c shows the effect of making the up-dip pillar wall perpendicular to the dip of the orebody. Although the failure zone is slightly reduced it still extends across the complete pillar width.

In actual mining practice a horizontal floor is left at the bottom of each apparent dip stope for operating the trackless equipment. Hence the full height is not exposed on the up-dip side of the pillar. This configuration is illustrated in Fig. 14d. In this case spalling is confined to the top left-hand and bottom right-hand corners of the pillar. Across the pillar centre the safety factor ranges from 1.0 to 1.5, and hence the pillar should be stable. This improved pillar stability is due to the major principal stress, oriented at about 40° down-dip of the vertical, passing more easily through this type of pillar configuration. These results also indicate that benching the floor on completion of stoping could cause pillar failure similar to that shown in Fig. 14b.

CONCLUSIONS

The boundary element computer program accurately predicts zones of high stress concentrations, pillar spalling and floor heave for the almost homogeneous, elastic, quartzite rocks in the Elliot Lake uranium mines.

Changing the orientation of the walls of sill and crown pillars from vertical to perpendicular to dip did not result in any significant improvement in pillar stability. Increased pillar stability would probably be better improved by increasing their width, especially of the crown pillar.

Stability of identical pillars laid out on apparent dip, rather than true dip is reduced by about 20% (for a 20° dipping orebody). Again making the up-dip pillar wall perpendicular rather than vertical resulted in no significant improvement. However, leaving a bench on the up-dip side did result in improved stability of these apparent dip pillars.

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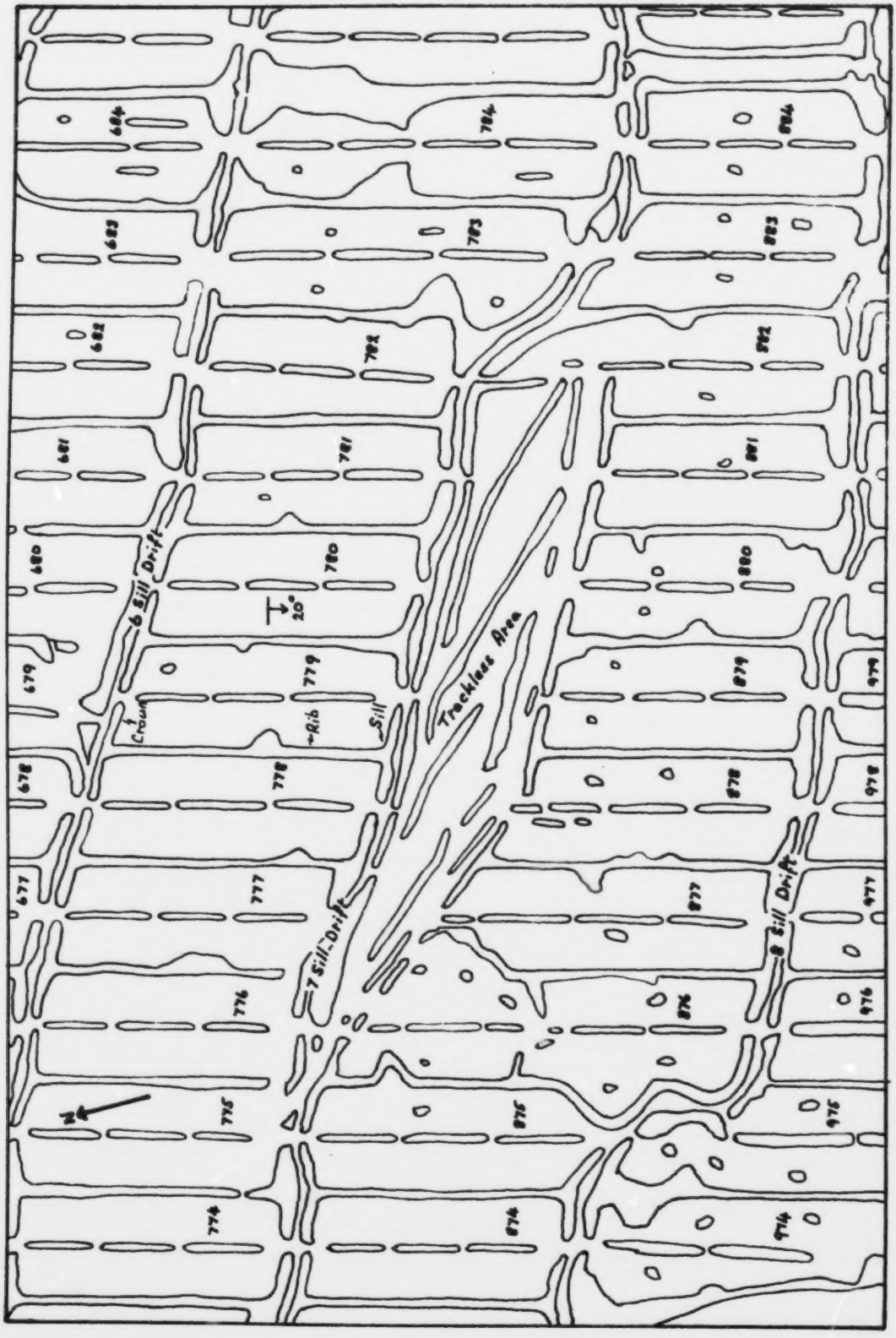

Fig. 1 - Stope and pillar layout of east area of Quirke Mine.

Fig. 2 - Spalling of up-dip corner of sill drift.

Fig. 3 - Cracks on down-dip corner of sill drift.

Fig. 4 - Spalling of down-dip side of crown pillar.

Fig. 5 - Cracks on up-dip side of sill pillar.

Fig. 6 - Crushing at top of centre rib pillar.

Fig. 7 - Floor cracks at bottom of a stope.

Fig. 8 - Rockburst in 7-sill pillar.

Fig. 9 - Floor heave in trackless area.

Fig. 10 - Floor heave in 7-sill drift.

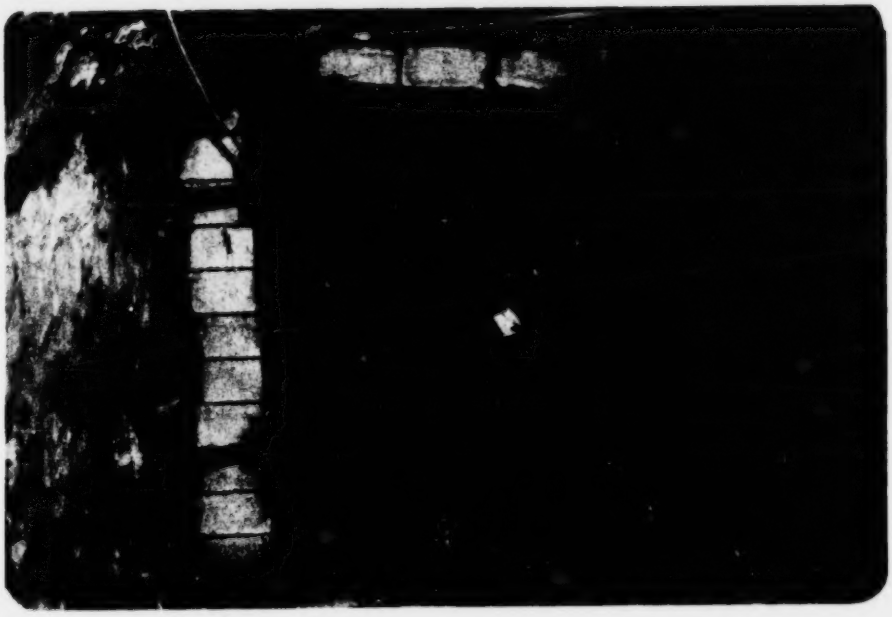

Fig. 11 - Buckling of ventilation door frames in 7-sill drift.

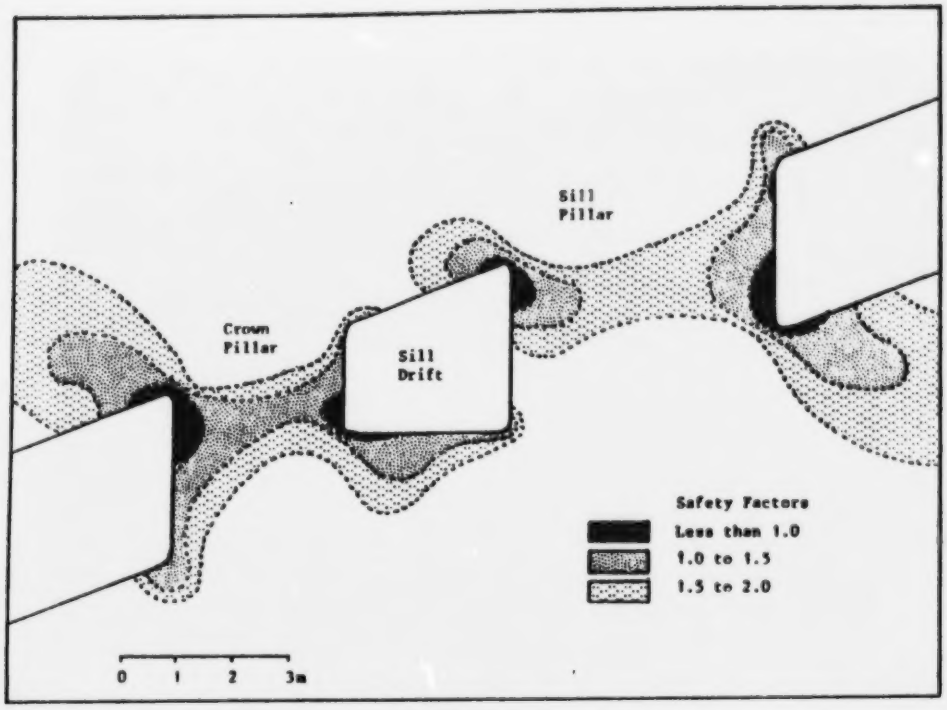

Fig. 12a - Sill and crown pillars with vertical walls.

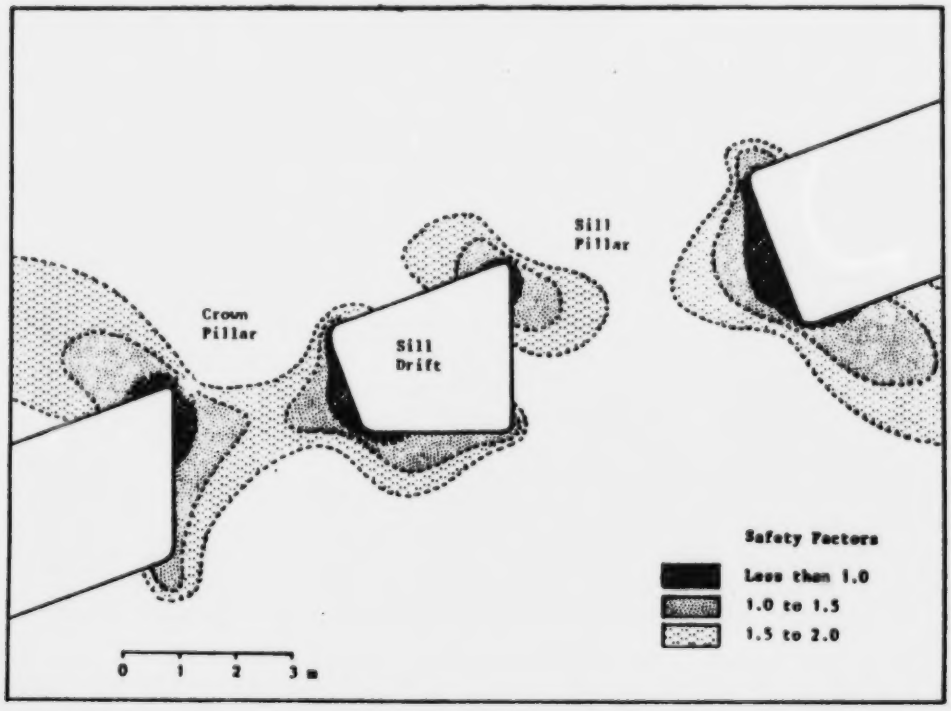

Fig. 12b - Sill and crown pillars with two vertical and two perpendicular walls.

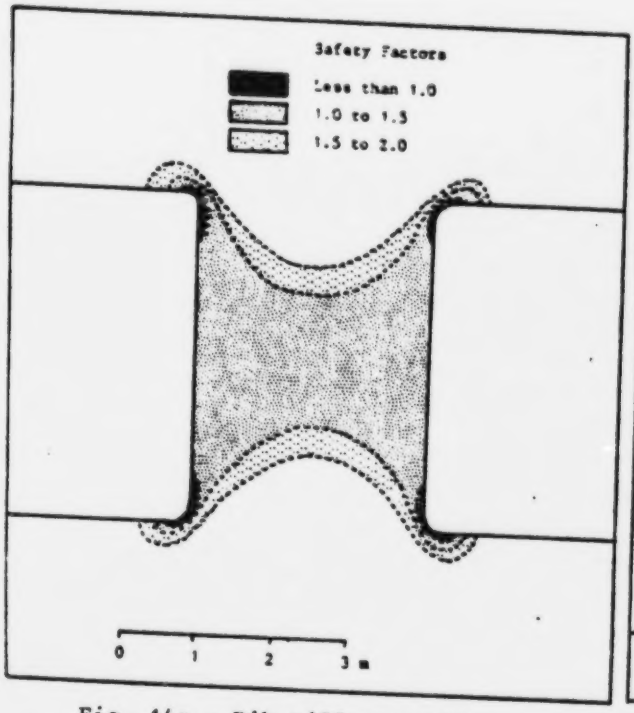

Fig. 14a - Rib pillar on dip.

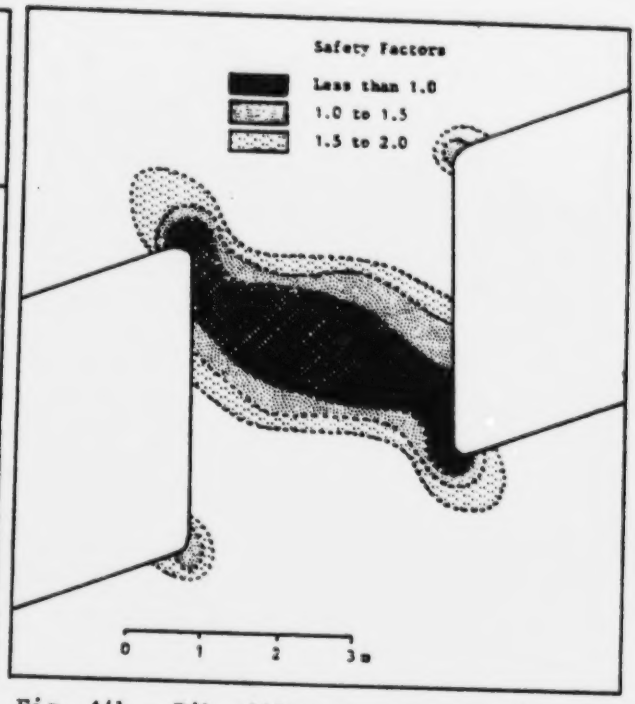

Fig. 14b - Rib pillar on apparent dip.

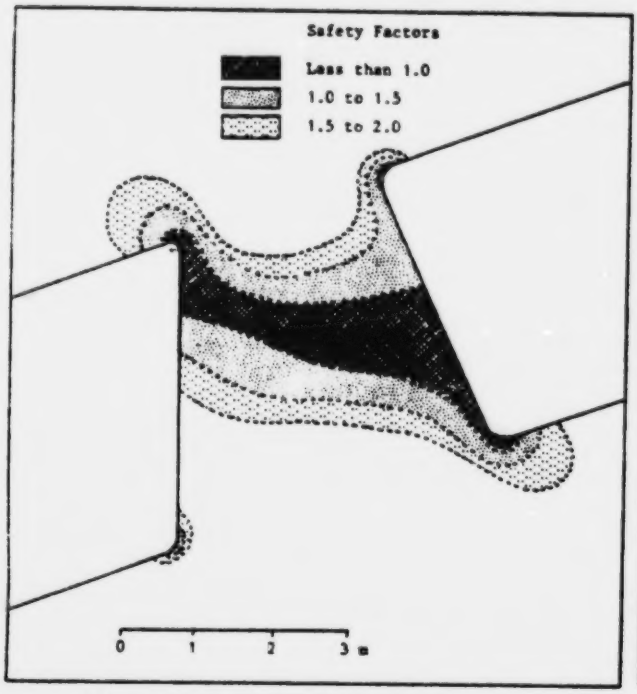

Fig. 14c - Rib pillar with vertical and perpendicular walls.

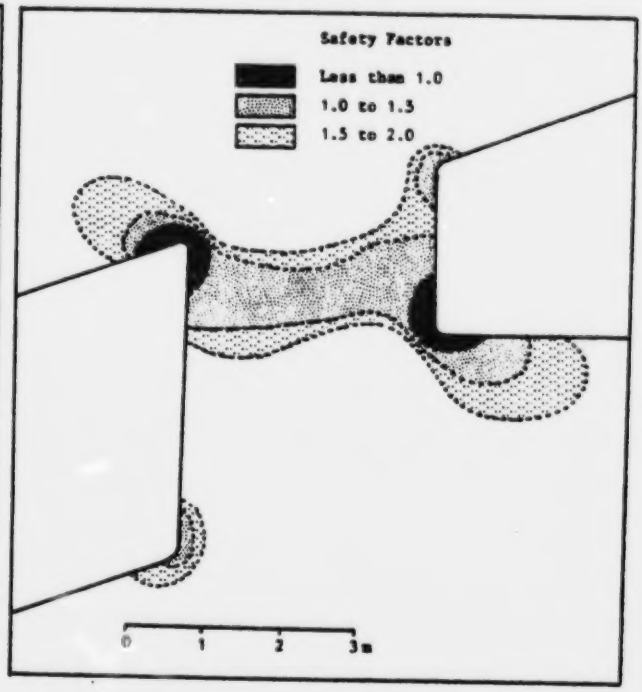

Fig. 14d - Rib pillar with up-dip bench.

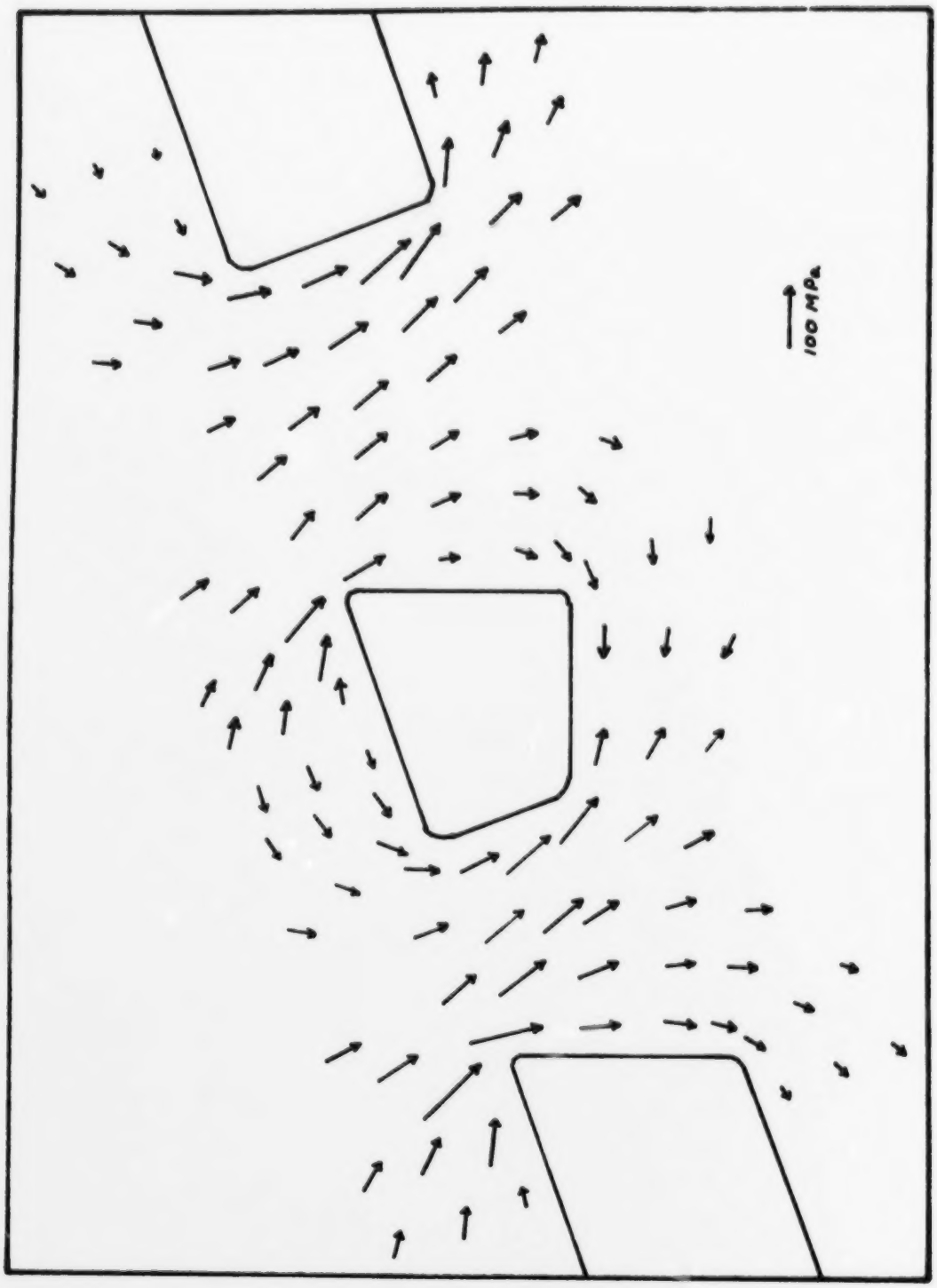

Fig. 13 - Magnitude and directions of principal stress.